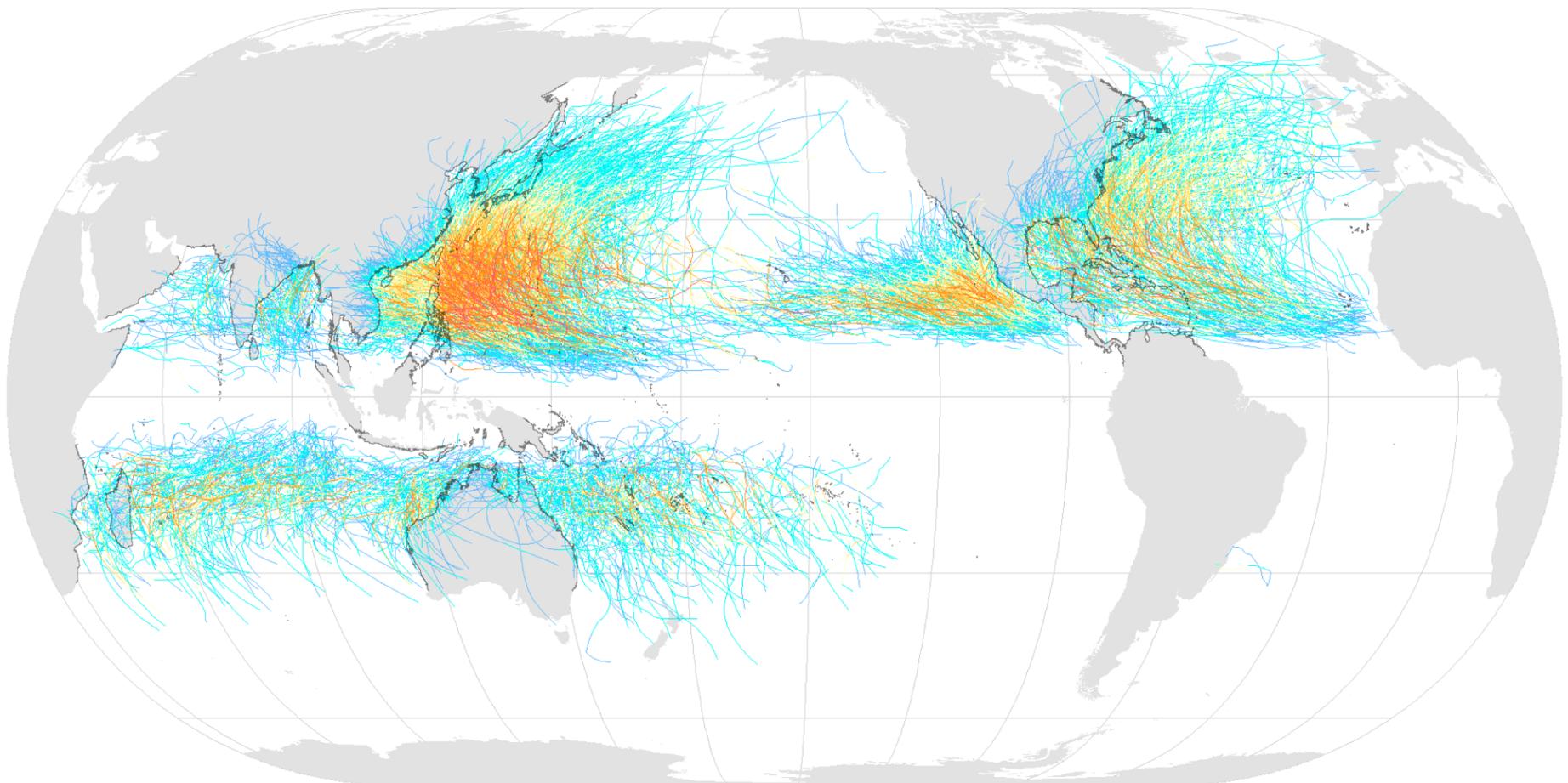




Hurricanes and Climate Change

Kerry Emanuel
Massachusetts Institute of Technology

Tropical Cyclones, 1945–2006



Saffir-Simpson Hurricane Scale:

tropical depression

tropical storm

hurricane category 1

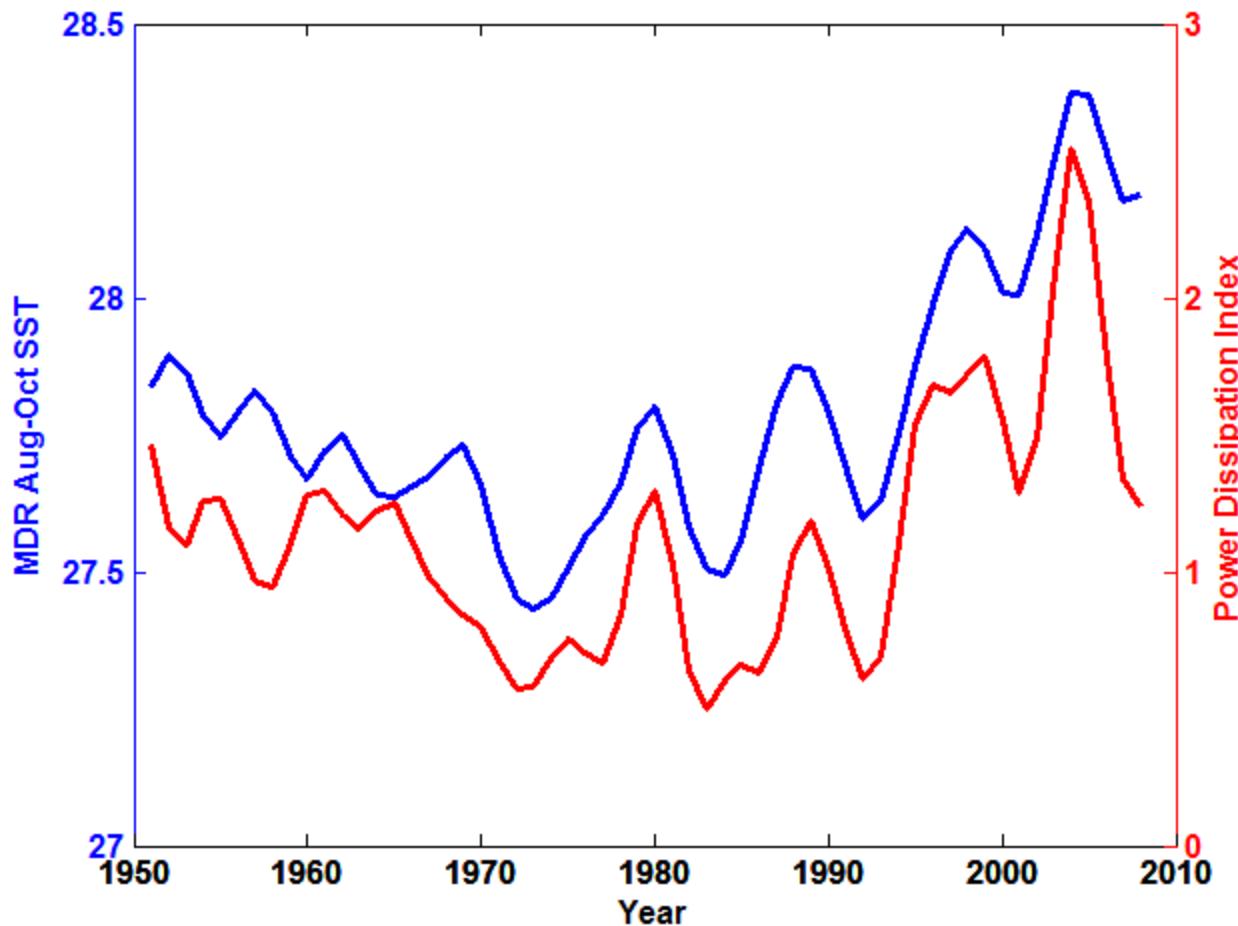
hurricane category 2

hurricane category 3

hurricane category 4

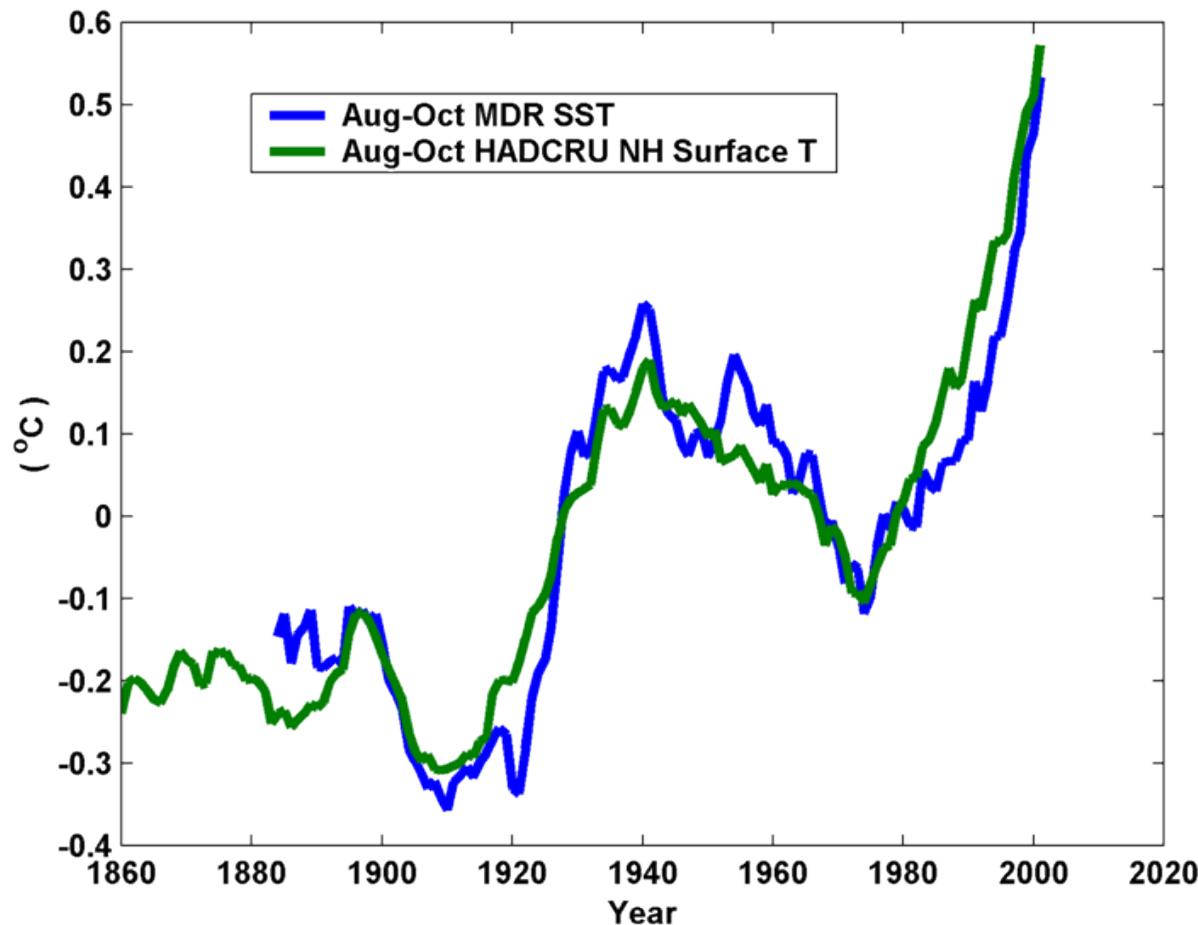
hurricane category 5

Atlantic hurricane power has more than doubled over the past 30 years

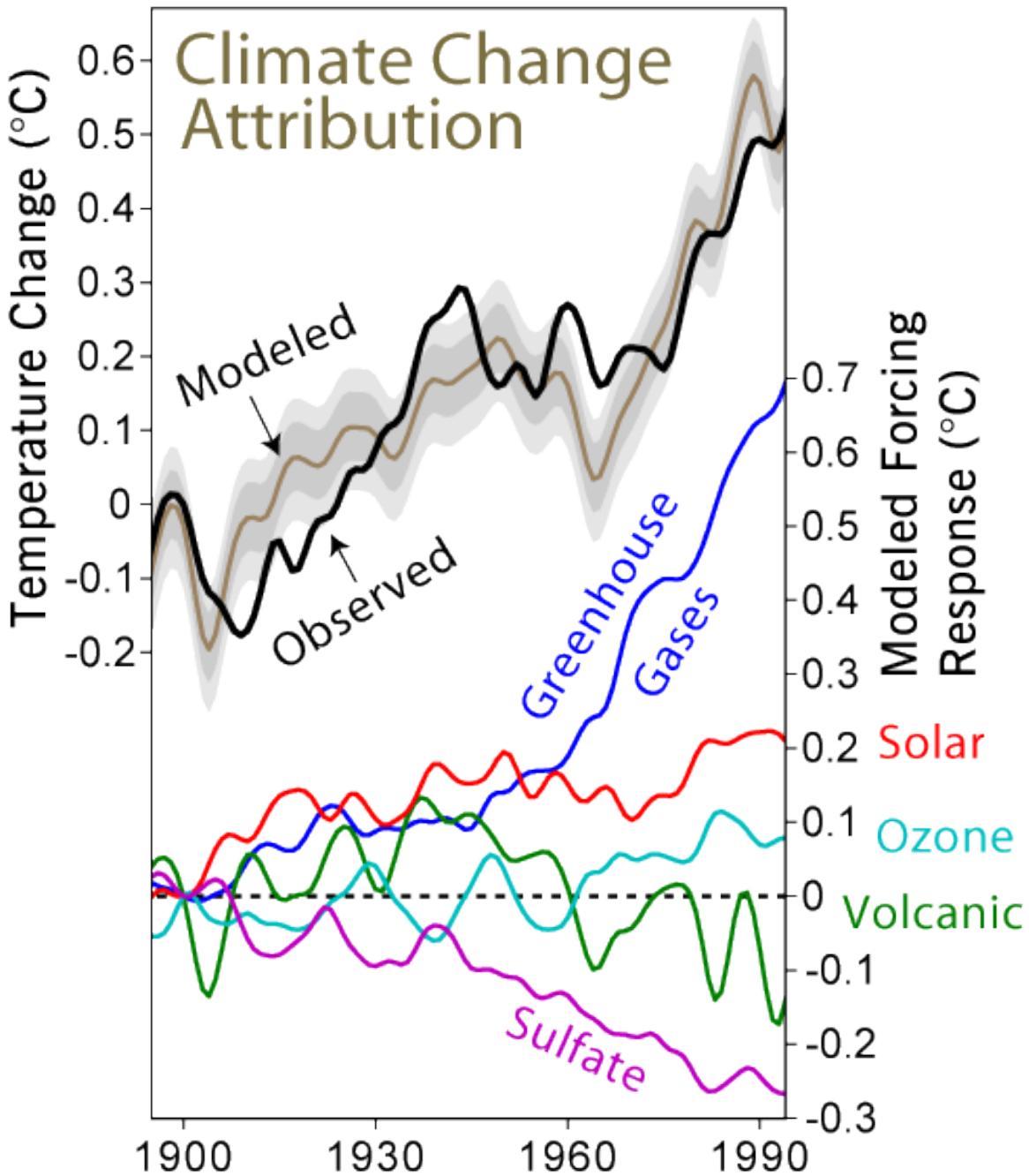


Doubling of Atlantic PDI for ~0.5 C increase in SST

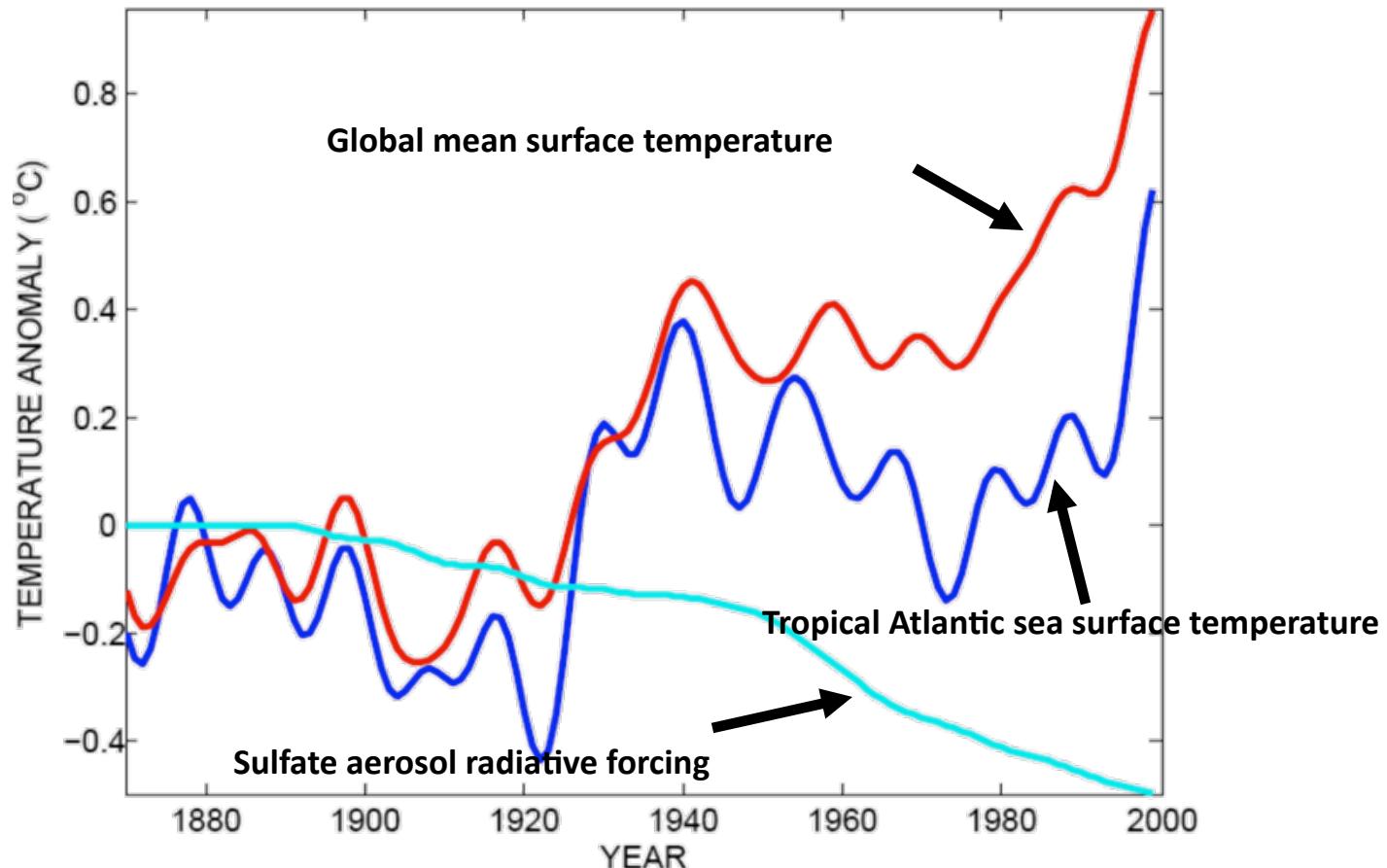
Summertime Tropical Atlantic Sea Surface Temperatures Track Northern Hemisphere Temperature on Decadal Time Scales



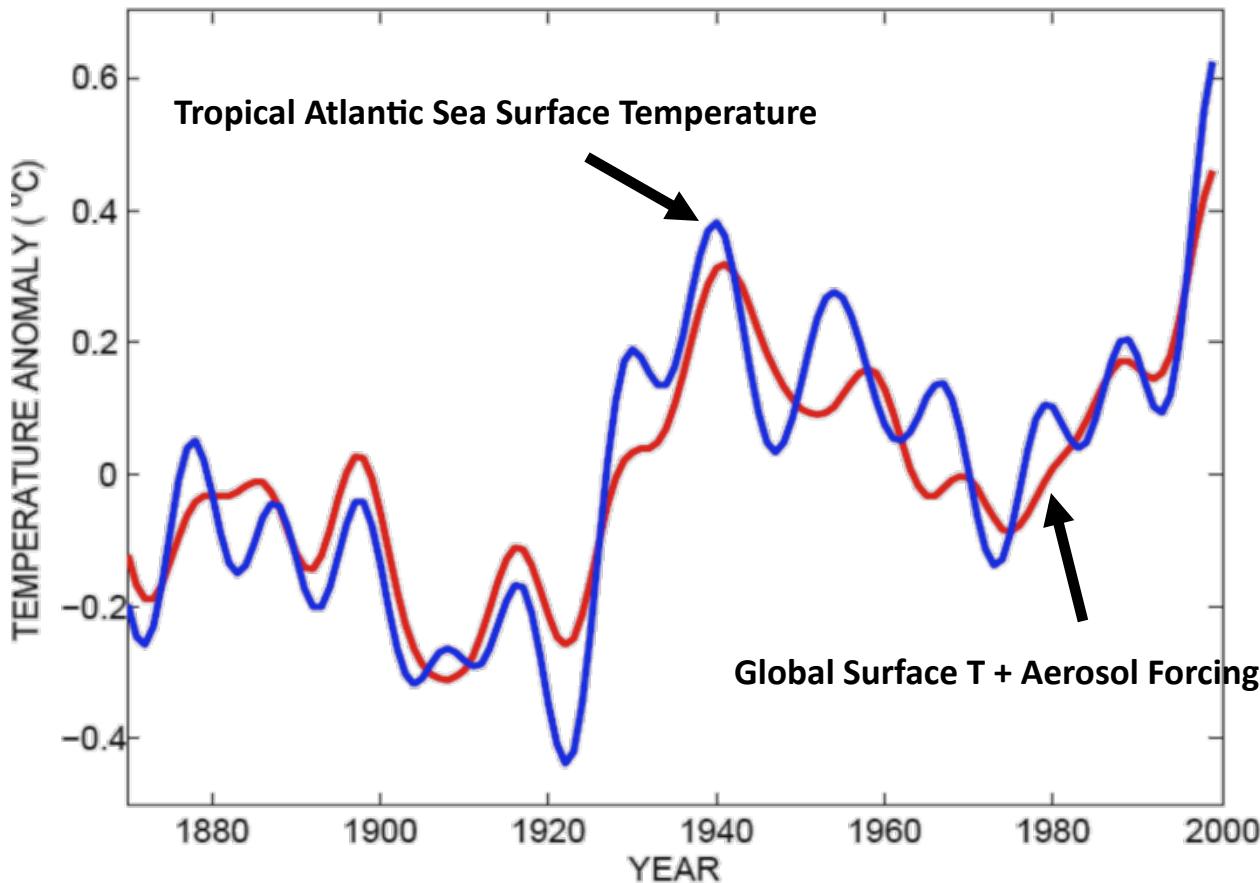
10-year Running Average of Aug-Oct Northern Hemisphere Surface Temp and Hurricane Region Ocean Temp



Tropical Atlantic SST(blue), Global Mean Surface Temperature (red) Aerosol Forcing (aqua)



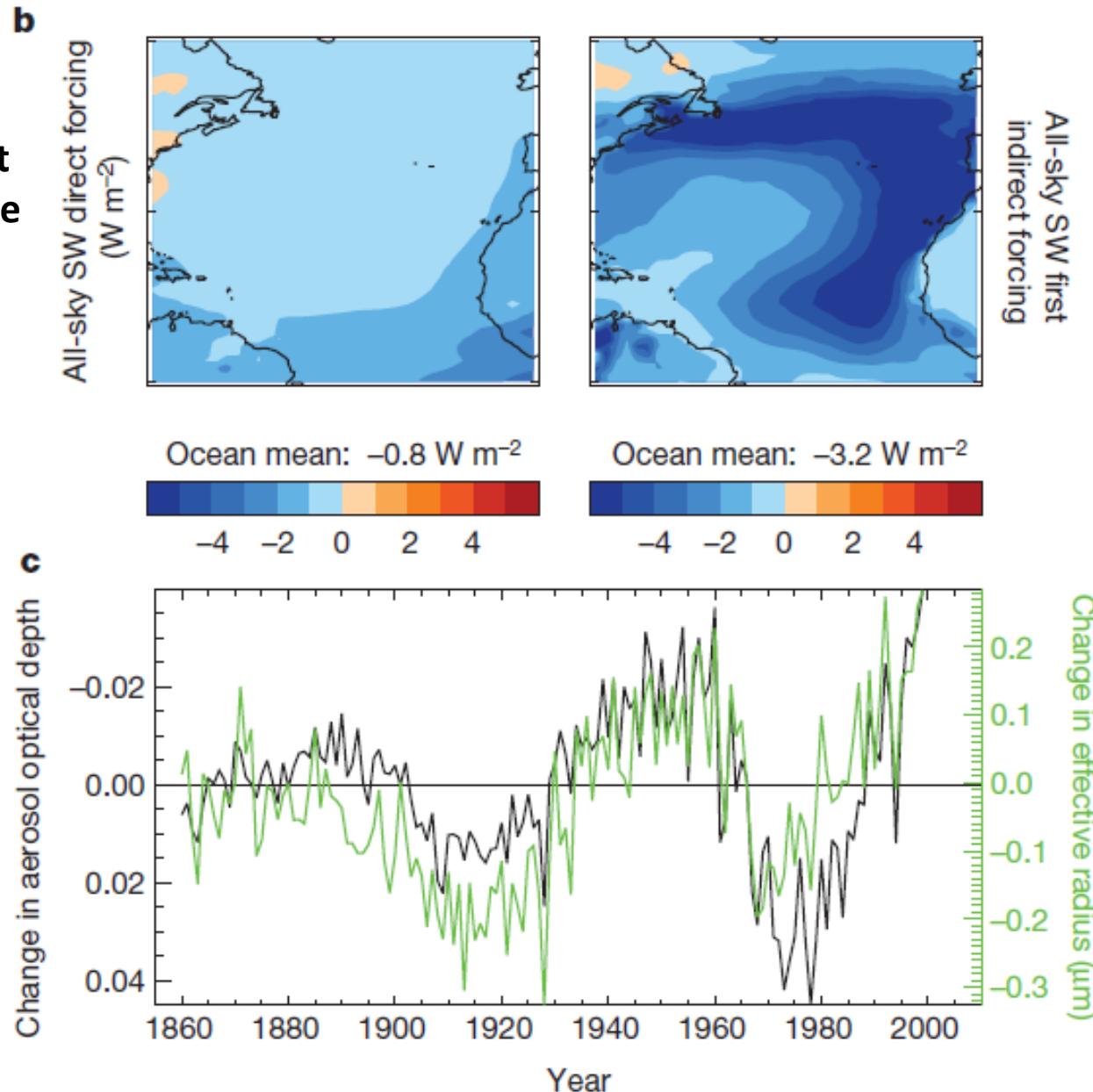
Best Fit Linear Combination of Global Warming and Aerosol Forcing (red) versus Tropical Atlantic SST (blue)



**Direct (left) and indirect
(right) aerosol shortwave
forcings**

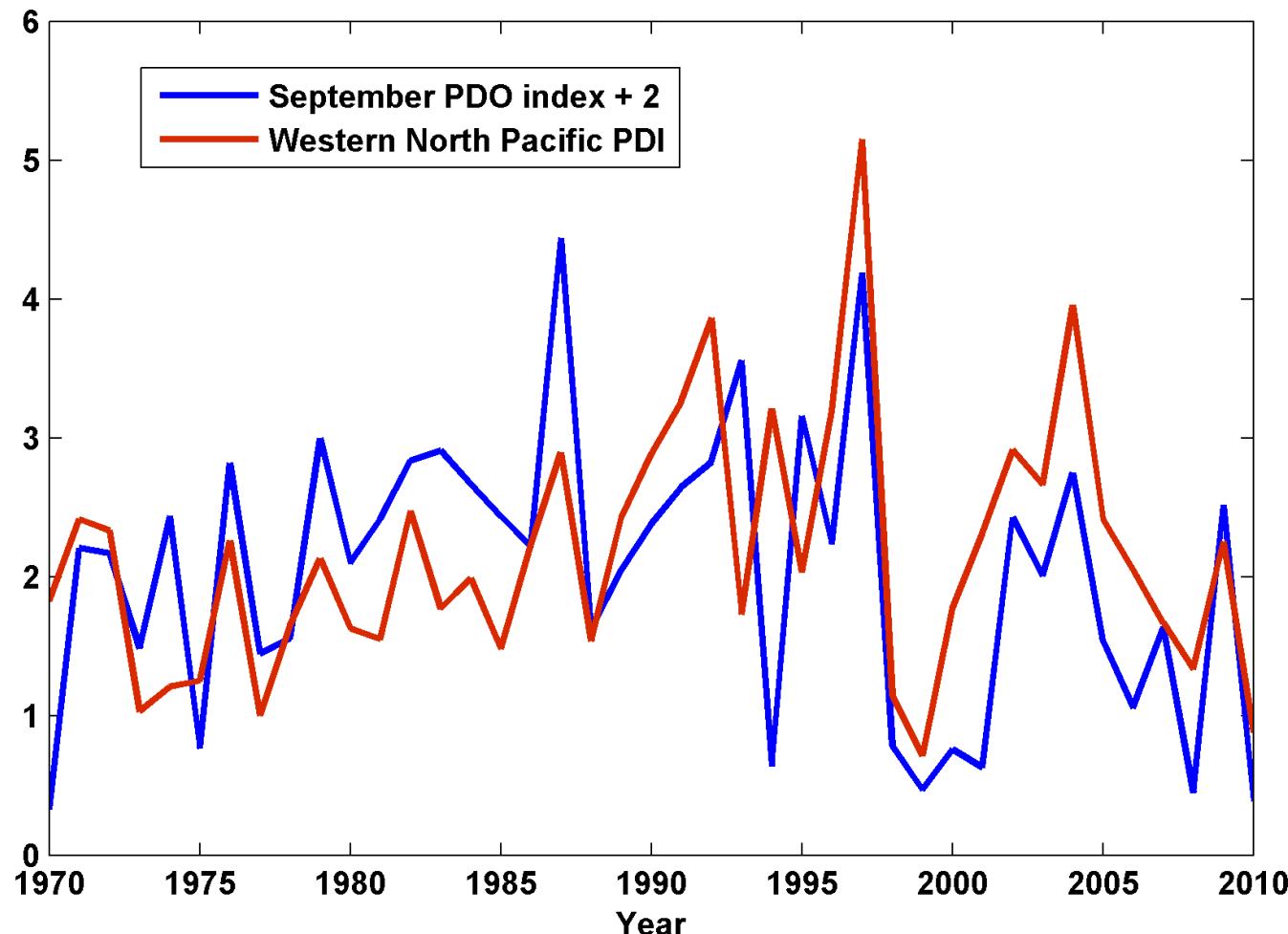
**Booth et al., Nature,
2012**

**Detrended time series
of aerosol optical
depth and effective
radius**

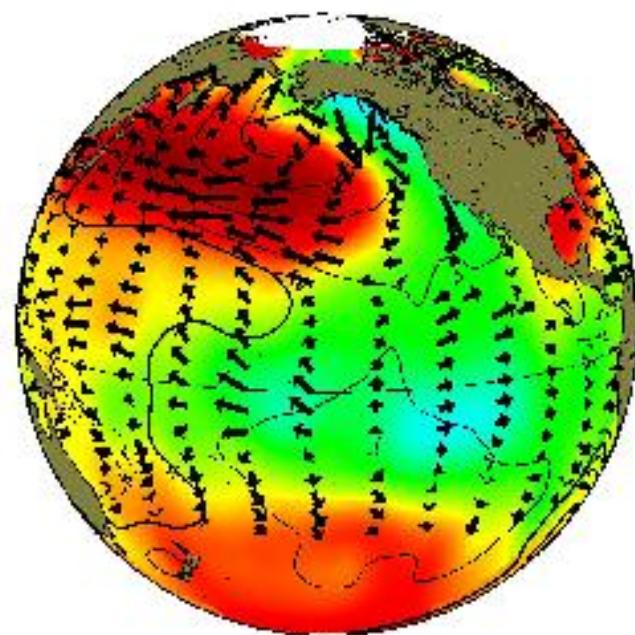
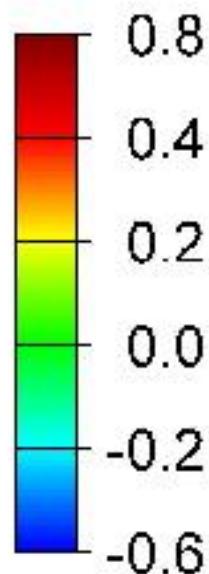
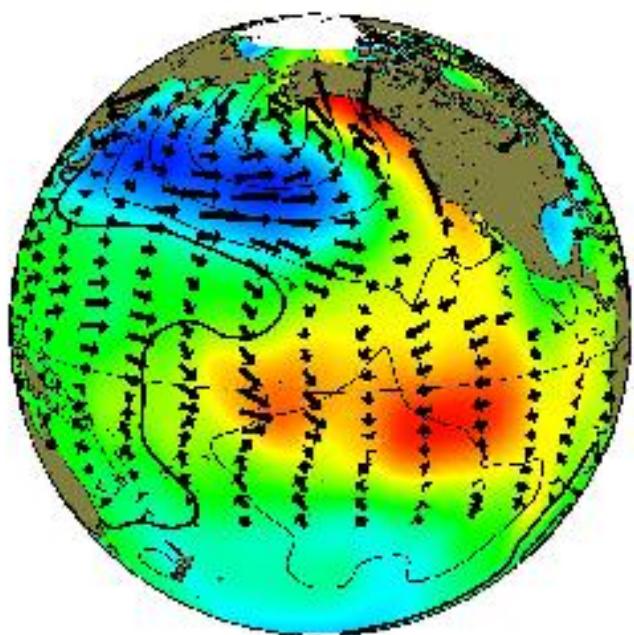


What about the Pacific?

Western North Pacific: Hurricane Activity Strongly Relate to the Pacific Decadal Oscillation (PDO)



PDO Pattern



Summary

- Tropical cyclones account for the majority of insured losses worldwide
- Atlantic hurricane power has more than doubled since the 1980s
- Atlantic hurricane power tracks summer tropical Atlantic ocean temperature
- Summer Atlantic ocean temperature seems to be controlled by radiative forcing, including greenhouse gases
- Tropical cyclone activity in the western North Pacific region seems to be dominated by a natural climate oscillation there.

Tropical Cyclones Tracks: What will happen in warming world?

Suzana J. Camargo
Lamont-Doherty Earth Observatory
Columbia University

Project collaborators:
Kerry Emanuel (MIT), Adam Sobel (Columbia University), Timothy Hall (NASA GISS) and James Kossin (NOAA)

Questions being investigated

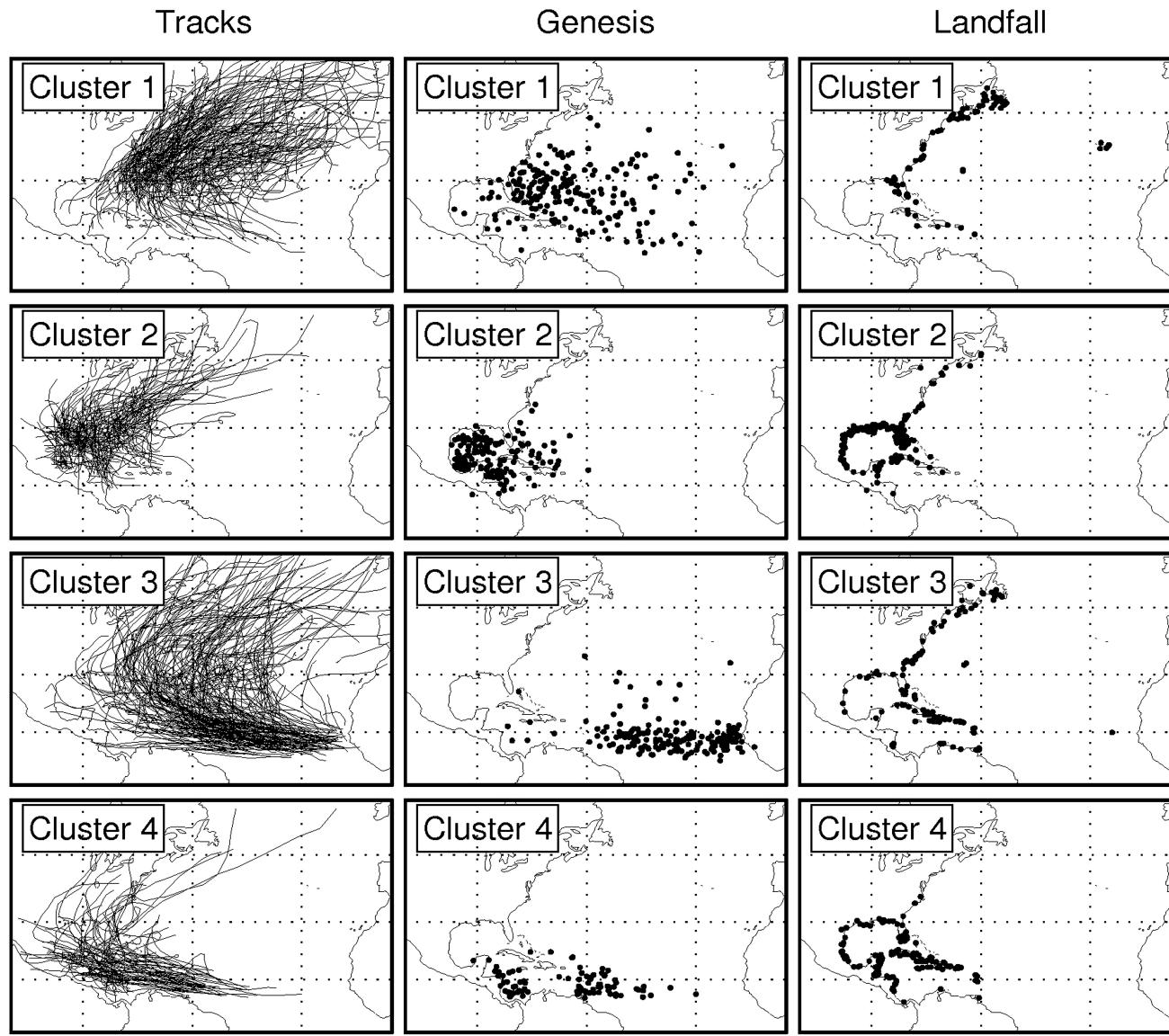
- Are there robust and significant changes in tropical cyclone tracks (globally and regionally) in a warming world?
- If there are significant changes, what are the causes for these changes?
- Is there predictability for track changes?

Methodology to investigate track changes

- Use cluster analysis as a diagnostic for track changes under a warming climate.
- Tracks from dynamical models (CMIP5 and other model simulations)
- Tracks from statistical-dynamical downscaling (Kerry Emanuel MIT)
- Tracks from statistical models (Tim Hall, NASA GISS)

Cluster Analysis of North Atlantic Tropical Cyclone Tracks

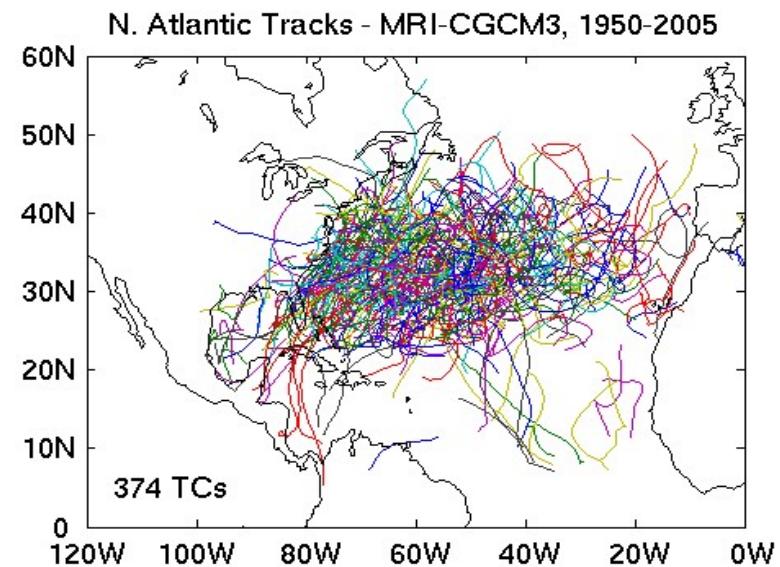
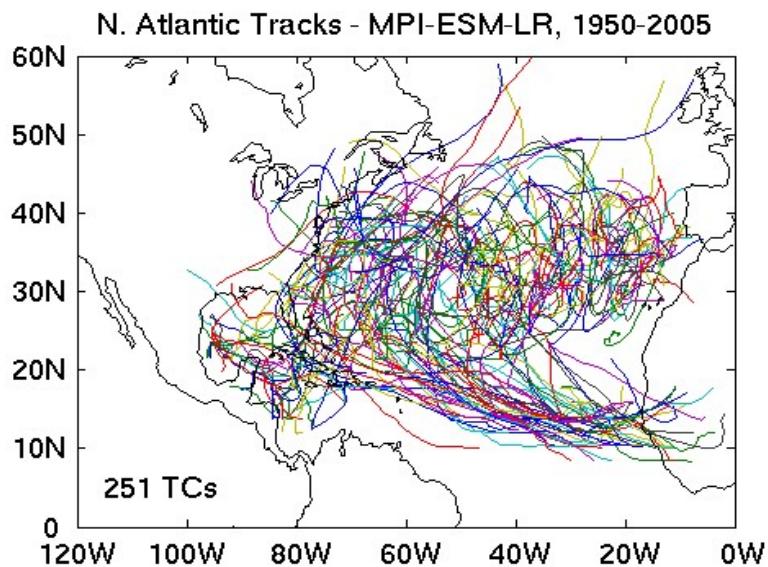
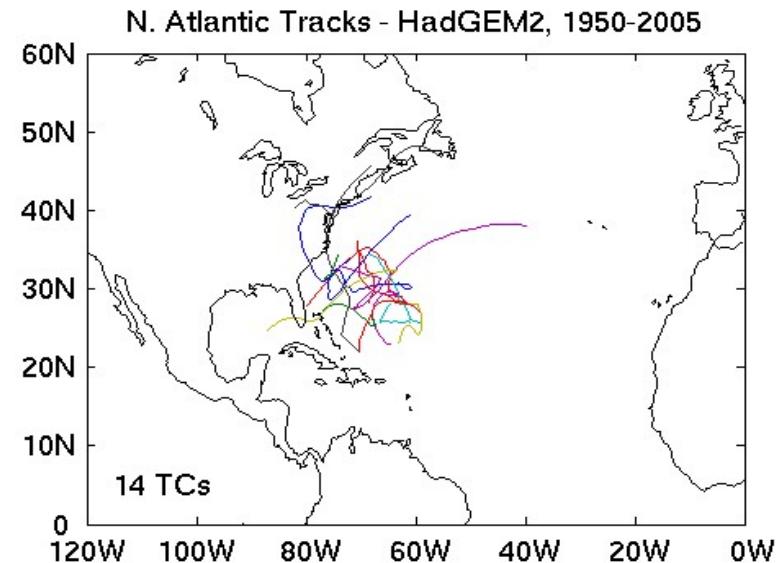
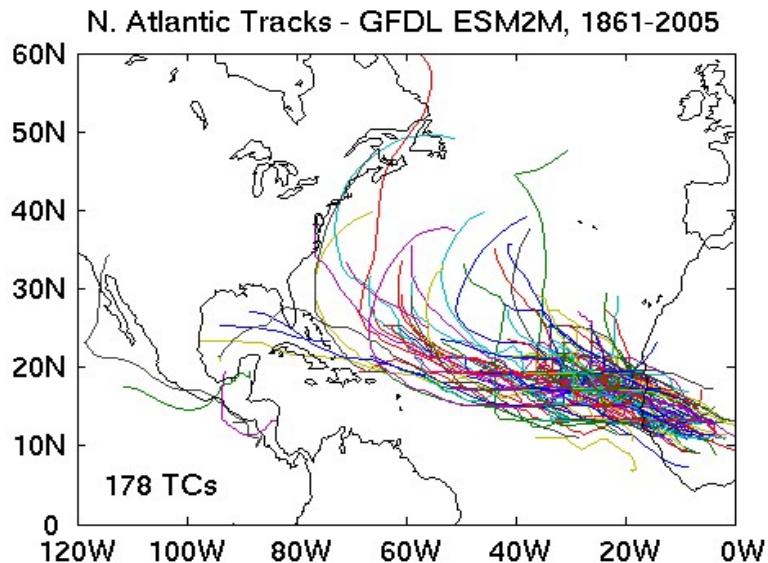
Kossin, Camargo and Sitkowski, 2010



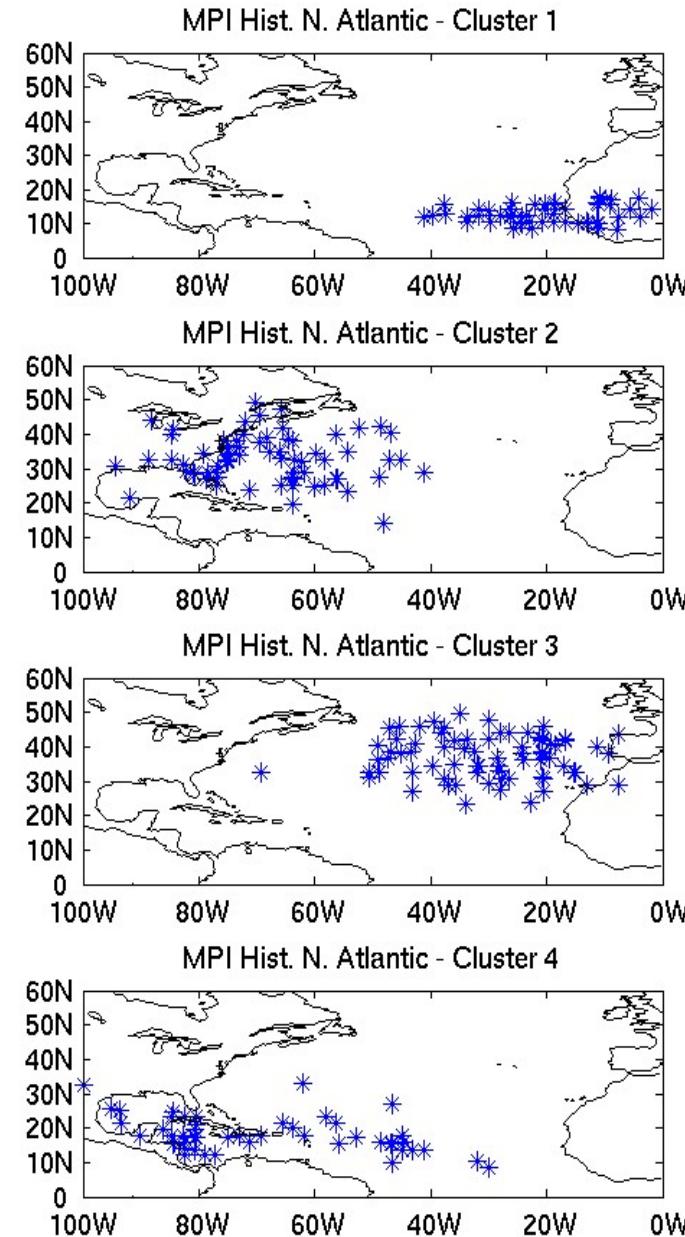
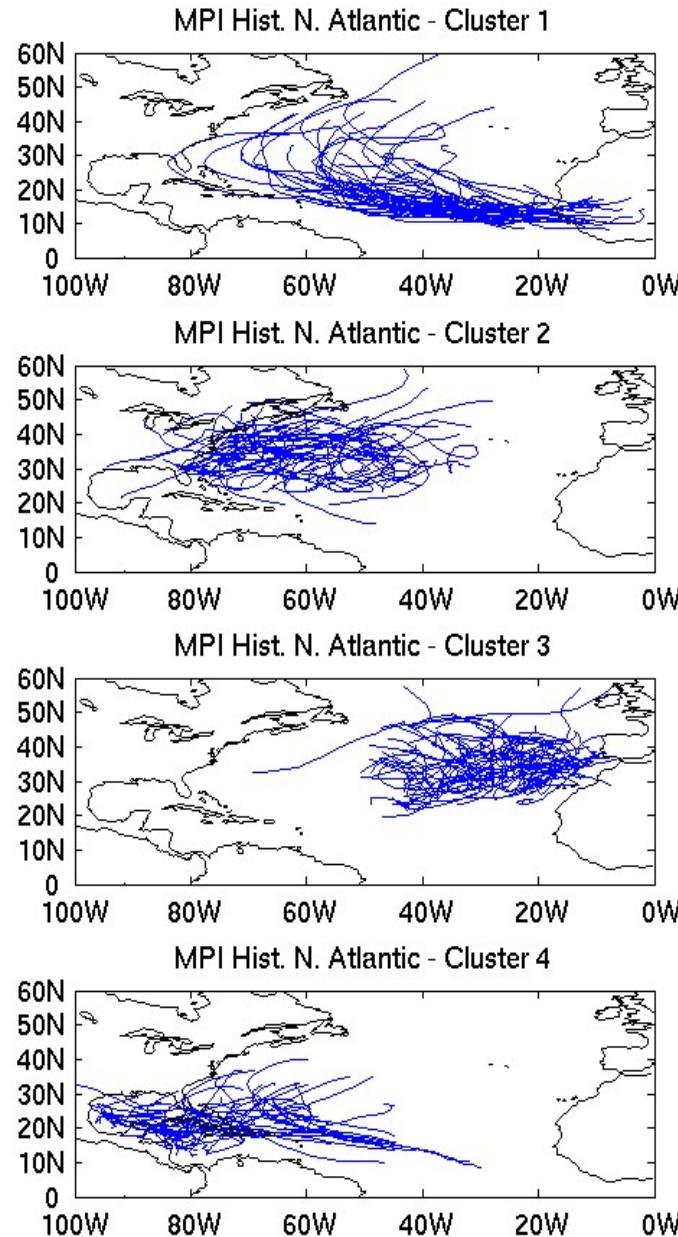
Preliminary Results from a few CMIP5 models in the North Atlantic

- Models:
 - GFDL ESM2M
 - HadGEM2
 - MPI
 - MRI CGCM3
- Scenarios:
 - Historical
 - RCP45 and RCP85

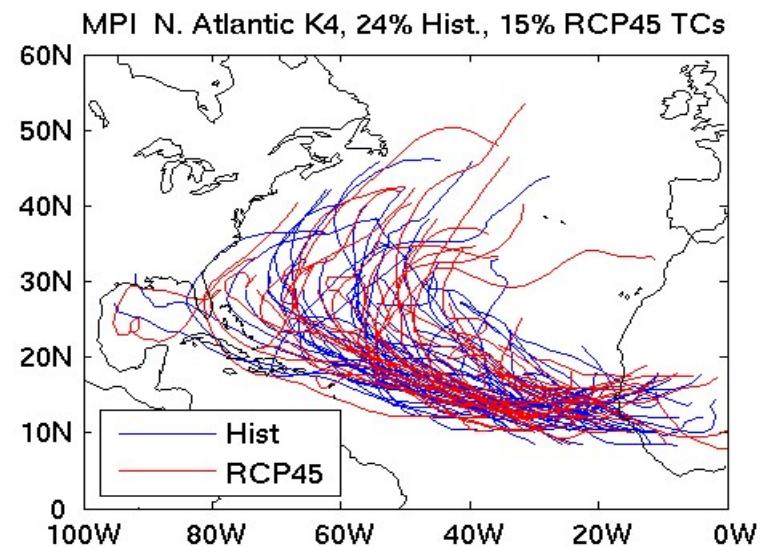
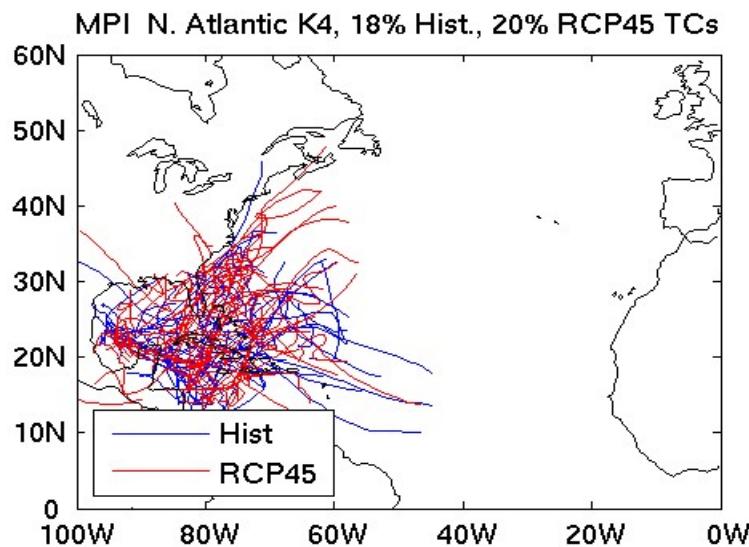
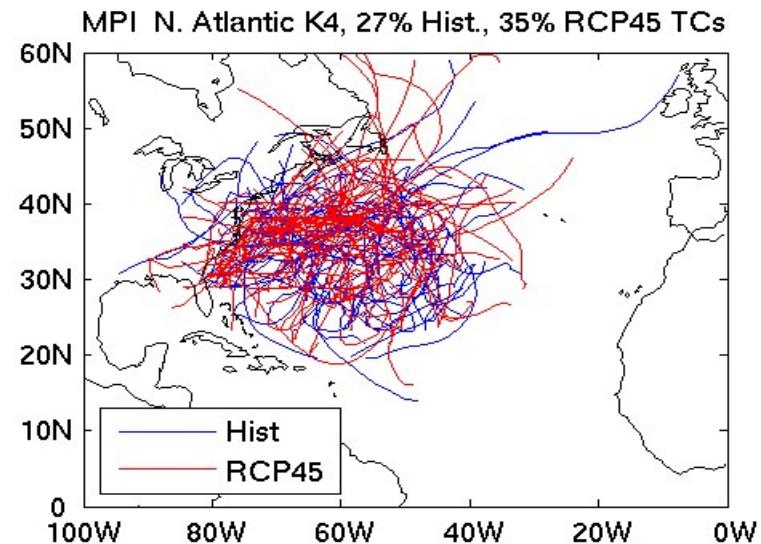
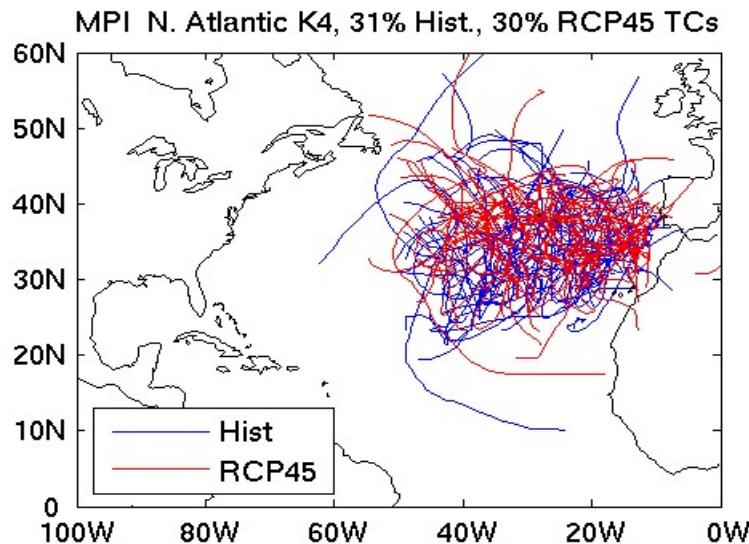
CMIP5 models – Historical runs



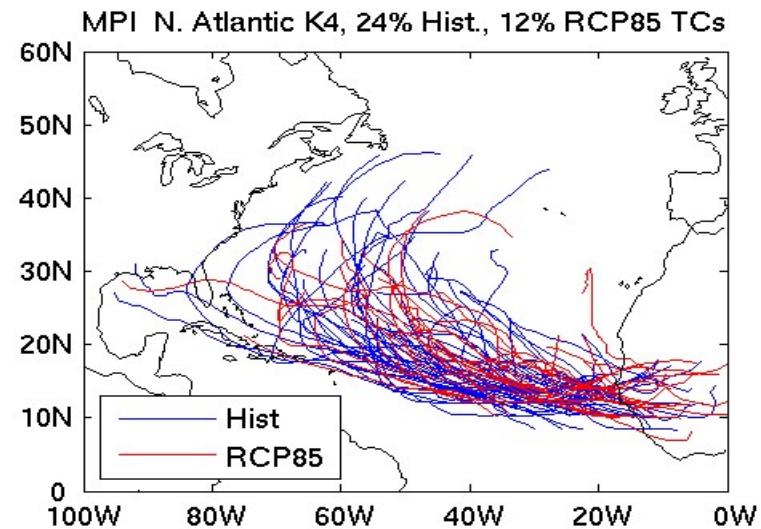
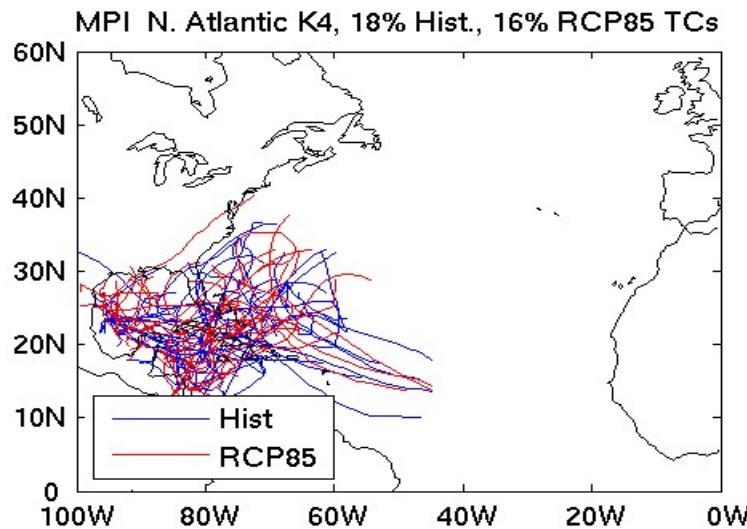
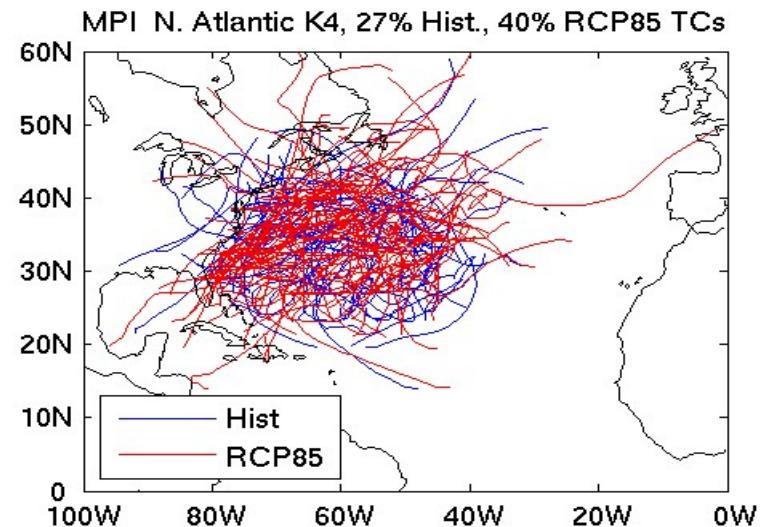
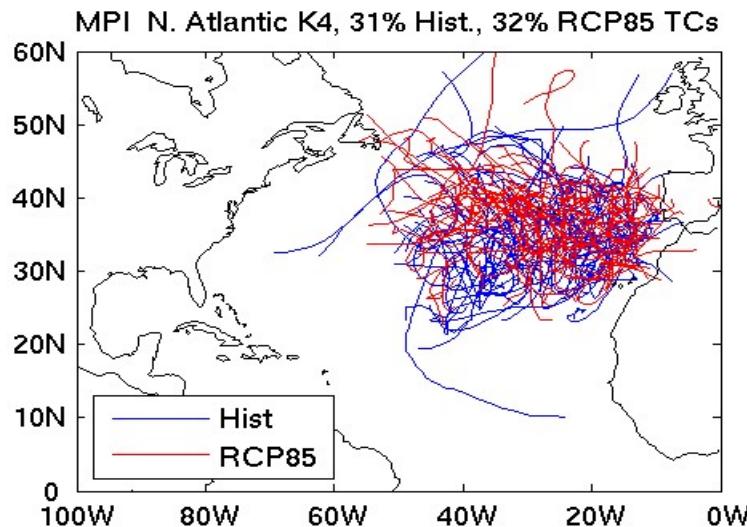
MPI – Clusters K4 - Historical tracks



MPI - Historical & RCP45



MPI – Historical and RCP85



Next steps:

- Apply cluster analysis to other climate models in the North Atlantic
- Examine the optimal way to apply cluster analysis to many models and multiple scenarios.
- Determine statistical significance of track changes
- Apply the methodology to other regions (western North Pacific, southern hemisphere, etc)
- Analysis of statistical-dynamical and statistical tracks under historical and warming conditions